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DIGITAL X-RAY CAMERA

CROSS-REFERENCE TO RELATED APPLICATION

5 This application claims priority of U.S. Patent Application Serial No. 60/546,575, filed on February 20, 2004, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

10 The invention generally relates to x-ray devices and methods for using the same. More particularly, the invention relates to portable x-ray devices that contain an unattached x-ray detector, methods for using such portable x-ray devices as a digital x-ray camera, and systems containing such portable x-ray devices.

BACKGROUND OF THE INVENTION

15 Typical x-ray tubes and x-ray devices (device containing x-ray tubes) have been known and used for some time. Unfortunately, they are usually bulky and are powered by heavy, high-voltage power supplies that restrict mobility. As well, they are often difficult and time-consuming to use. In many instances, a sample for analysis must be sent to an off-site laboratory for analysis by the x-ray device.

20 These limitations can be very inconvenient for many popular uses of x-ray devices containing them. Such uses include x-ray fluorescence (XRF) of soil, water, metals, ores, well bores, etc., as well as diffraction and plating thickness measurements. Typical x-ray imaging

applications require the sample to be imaged to be brought to the x-ray device. These limitations have led to an increased interest in making x-ray devices portable. See, for example, U.S. Patent Nos. 6,661,876, 6,459,767, 6,038,287, and 6,205,200; U.S. Published Patent Applications 2003/0048877, 2003/0002627, and 2003/0142788; and European Patent  
 5 Nos. EP0946082, EP0524064, EP0247758, EP0784965, and EP0488991; the entire disclosures of which are incorporated herein by reference.

Many of these existing designs increase the portability of x-ray devices. At the same time, however, these designs are limited for several reasons. First, most of the designs are not truly portable since they have an external power source (i.e., require utility-supplied line  
 10 voltage). Second, while some of the portable designs, especially the XRF systems, have internal or "integrated" power supplies, they don't have the high x-ray tube current load that is often necessary for x-ray imaging. For example, energy-dispersive XRF typically requires x-ray beam currents of less than 1 milliampere while x-ray imaging typically requires greater than about 2 milliamperes. Finally, the radiation shielding for the x-ray tubes usually  
 15 comprises lead, which is quite heavy and limits the portability of the device.

A further limitation on design of the increased portability is the image display components. High-quality imaging displays for displaying the results of the x-ray analysis are difficult to integrate into the design of the housing of the portable x-ray device. Consequently, many of the portable designs have the image display component external to the chassis or  
 20 housing containing the x-ray tube.

## SUMMARY OF THE INVENTION

The invention relates to portable x-ray devices and methods for using such devices. The x-ray devices have an x-ray tube powered by an integrated power system. The x-ray tube is shielded with a low-density insulating material containing a high-Z substance. The x-ray devices can also have an integrated display component. With these components, the size and weight of the x-ray devices can be reduced and the portability of the devices enhanced. The x-ray devices can also have detecting means that is not structurally attached to the device and therefore is free standing. Consequently, the x-ray devices can also be used as a digital x-ray camera. The portable x-ray devices are especially useful for applications where portability is an important feature such as in field work, remote operations, and mobile operations such as nursing homes, home healthcare, or teaching classrooms. This portability feature can be particularly useful in multi-suite medical and dental offices where a single x-ray device can be used as a digital x-ray camera in multiple offices instead of requiring a separate device in every office.

## BRIEF DESCRIPTION OF THE DRAWINGS

The following description of the invention can be understood in light of the Figures, in which:

Figures 1-2 depict the x-ray device in one aspect of the invention;

Figure 3 depicts the x-ray device in another aspect of the invention;

Figure 4 depicts the x-ray device in another aspect of the invention;

Figure 5 depicts the x-ray tube and power supply of the x-ray device in one aspect of the invention;

Figures 6-7 depict the power source of the x-ray device and method for connecting the power source to the x-ray device in one aspect of the invention;

5 Figure 8 depicts the x-ray tube of the x-ray device in one aspect of the invention;

Figure 9 depicts a conventional x-ray tube in a conventional configuration;

Figures 10-12 depicts the x-ray device in one aspect of the invention; and

Figures 13-17 depicts the x-ray in another aspect of the invention.

10 Figures 1-17 illustrate specific aspects of the invention and are a part of the specification.

In the Figures, the thickness and configuration of components may be exaggerated for clarity. The same reference numerals in different drawings represent the same component. Together with the following description, the Figures demonstrate and explain the principles of the invention.

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#### DETAILED DESCRIPTION OF THE INVENTION

The following description provides specific details in order to provide a thorough understanding of the invention. The skilled artisan, however, would understand that the invention can be practiced without employing these specific details. Indeed, the invention can  
20 be practiced by modifying the illustrated method and resulting product and can be used in conjunction with apparatus and techniques conventionally used in the industry. While the

invention is described for use in x-ray imaging for dental purposes, it could be used in other medical applications such as medical imaging, veterinary, and bone densitometry. As well, it could be used for non-dental and non-medical applications such as industrial imaging, metal fatigue inspections, weld-inspection for cracks/voids and pipes, for security inspections  
 5 allowing random inspection of parcels and carry-on baggage, and the like.

As described above, the invention includes a portable x-ray device that is used primarily for remote and/or office applications, including in multi-suite office locations. The x-ray device can be designed to be either handheld or temporarily fixed to a given location, such as a tripod-mount operation. As well, the invention could be mounted on any other semi-stable  
 10 apparatus, such as an articulating arm or C-arm as commonly used in radiology applications and described in the publications mentioned above.

The x-ray device of the invention is portable in that it can be transported by hand carrying it from one location to a second location without support by any mechanical apparatus. Because it uses an integrated power system, the location of its use can be independent of any  
 15 external fixed power source, such as utility-supplied AC voltage often required in the home or office. As well, the x-ray device contains detecting means that is not structurally attached to the device and therefore is free standing. This independence from an external power source and free-standing detecting means are particularly useful features of the x-ray devices of the invention.

20 In the aspect of the invention shown in Figures 1-2, the x-ray device 10 of the invention contains a housing or chassis 20 to contain all the internal components of the device. The

housing 20 encloses an x-ray tube 30 for producing the x-rays. The x-ray device 10 contains a power system (including power source 40) to provide power for the device 10 and means for detecting the x-rays, such as film, CCD sensors, or imaging plates (not shown). The x-ray device 10 also contains means for displaying the results of the analysis such as an integrated  
5 image display screen 60 (shown in Figure 4); control means such as controller 70; and radiation shielding 80 to shield the operator of the device from backscattered radiation from the sample.

The x-ray device 10 also contains any other components known in the art for efficient operation (such as x-ray collimator 32), including those components described in the  
10 documents mentioned above.

The x-ray device 10 contains a unique system for providing power to the x-ray device. The power system of the x-ray device comprises a power source 40, power supply 34, and conversion means. The power source 40 used in the x-ray device of the invention can be any known in the art that can supply the desired amount of power, yet fit within the space  
15 limitations of the x-ray device. In one aspect of the invention, the power source comprises a battery, such as a 14.4V NiCd battery pack. The power source can be recharged by any suitable means, such as by connection to an appropriate voltage when using batteries that are re-chargeable.

In one aspect of the invention, the power source 40 is removable from the remainder of  
20 the x-ray device 10. In this aspect of the invention, the power source 40 comprises mechanical and electrical means for connecting the power source 40 to the x-ray device 10. The electrical

and mechanical connection means can be any of those known in the art. As depicted in Figure 6, the electrical connection means can comprise an extension member 41 with an electrical connector 42 contained in an upper portion thereof. The mechanical connection means comprises a release mechanism 43a.

5       As shown in Figure 7, the x-ray device 10 contains a locking mechanism 43b. To connect the power source 40 to the x-ray device 10, the power source 40 is gently pushed into the bottom of the handle 15 of the x-ray device 10. When completely connected, the electrical connector 42 connects with the internal electronics of the x-ray device 10. The locking mechanism 43b is automatically engaged to retain the power source 40 connected to the x-ray  
10   device 10 in this position. To remove the power source 40, the release mechanism 43a is actuated to unlock the locking mechanism 43b, and the power source 40 can be gently slid out from the handle 15.

The power source 40 is electrically connected to the conversion means using any connection means known in the art, including those described in the publications above. The  
15   conversion means converts the initial voltage supplied by the power source 40 to a converted voltage that is provided to the power supply 34. The conversion means generally converts the 14.4V (or similar voltage) provided by the power source 40 to a voltage ranging from about 80 to about 200V. In one aspect of the invention, the initial voltage is converted to a converted voltage of about 100V. Any conversion means known in the art that operates in this manner  
20   can be used in the invention, including the power management boards 36.

The conversion means is electrically connected to the power supply 34. The power supply 34 steps up the converted voltage (i.e., the 100V) provided by the conversion means to a voltage that can be used by the x-ray tube 30. The power produced by the power supply 34 and input into the x-ray tube 30 via connection 35 (shown in Figure 8) depends on the power  
5 needed to operate the x-ray tube, and the maximum power available from the power source. Generally, the power provided by the power supply 34 to the x-ray tube 30 can range from about 20 to about 150 kV. Typically, this power provided by the power supply can range from about 40kV to about 100kV.

In one aspect of the invention, the power provided by the power supply is provided by a  
10 plurality of individual power supplies. The number of individual power supplies used depends on the voltage needed for the x-ray tube, the space needed for the power supply 34, the total power available from the power source, and the number of electron-accelerating grids in the x-ray tube. In one aspect of the invention, the plurality of individual power supplies is two (as represented in Figure 5 by 45, 46) where 45 supplies positive voltage to the anode and 46  
15 supplies negative voltage to the cathode.

The power provided by each individual power supply depends on the number of individual power supplies used, the maximum power available from the power source, and the heat-dissipating capability of the x-ray tube. Generally, the power supplied by each individual power supply is the total power needed to operate the x-ray tube divided by the number of  
20 individual power supplies. For example, the power provided by each individual power supply (when there are 2) can range from about 20kV to about 50kV. In one aspect of the invention,



the power provided by each individual power supply (when there are 2) is about +35 kV and -35kV. In this embodiment, the +35 kV is attached to the anode of the x-ray tube and the -35 kV is attached to the cathode of the x-ray tube. A filament transformer is included in the cathode power supply to provide current to the x-ray tube filament and generate an electron beam at the cathode of the tube. The total power produced by the power supply is therefore the sum of the individual anode power supply and the individual cathode power supply.

When such individual low voltage power supplies are used, the x-ray tube 30 of the invention becomes more portable. Conventional x-ray tubes operate at much higher voltages in the range of 70 kV and higher. Because of these high voltages, and the need for the high voltage standoff, the conventional x-ray tube 300 is often encased in insulating oil 302 (or a similar material) within a liquid-tight case 306 as shown in Figure 9. The oil 302 also has the advantage of dissipating the high temperatures that existed during operation. By splitting the needed operation voltage into 2 (or more) individual power supplies, the individual power supplies only need to provide (and also stand off) half of the higher voltage.

With these lower voltages, the x-ray tube 30 of the invention can be encapsulated in materials other than high-density oil. These other materials need only insulate proportionately to the reduced voltage, i.e., these other materials need only insulate half as much as oil since the voltage produced is about half of that conventionally used. Any known material that can insulate in this manner can be used in the invention, including low-density materials like insulating gel, silicone rubber, epoxy, or combinations thereof. The insulating material is

provided in a layer 33 that substantially encapsulates the x-ray tube 30 except for that portion of the tube where x-rays are actually emitted by the tube (i.e., into the x-ray collimator 32).

The thickness of the layer of insulating material 33 need only be sufficient for the purpose indicated above. Generally, the thickness of the insulating material can range from about ¼ inch to about 1 inch. In one aspect of the invention, such as where silicone rubber is used, the thickness of the insulating material can range from about 1/3 inch to about ½ inch. In another aspect of the invention, the insulating material comprises a dual-layer around the x-ray tube with the first layer comprising one of the insulating materials and the second layer comprising another of the insulating materials.

Eliminating the need to use the high-density oil provides a significant reduction in the weight of the unit. An added advantage is that there is no need for a liquid-tight case 306 to hold the liquid oil 302. Indeed, when a solid material is used such as silicone rubber, there is no need for any case, even though one can optionally be used. In one aspect of the invention by removing the case, and instead using silicon rubber that is conformal with the x-ray tube, the total volume of the insulating material is reduced significantly.

As shown in Figure 9, conventional x-ray tubes 300 also contain a shielding to absorb stray x-rays that are emitted from the x-ray tube. The shielding usually was made of lead and incorporated into the liquid-tight case 306. Lead is conventionally used because of its excellent x-ray absorption properties. But lead shielding is quite heavy and consequently limits the portability of the x-ray device. With the x-ray device of the invention, this lead shielding has been eliminated, thereby increasing the portability by reducing the need for an

additional component in the x-ray device. Instead, the insulating material (i.e., silicone rubber) has dispersed within it a high-Z material. The high-Z material absorbs any stray x-rays that are emitted. Any high-Z material known in the art can be used, including compounds of Pb, W, Ta, Bi, Ba, or combinations thereof.

5           The concentration of the high-Z material in the insulating material need only be sufficient to absorb the expected amount of stray x-rays. Typically, the concentration of the high-Z material can range from about 30 wt% to about 60 wt%. In one aspect of the invention, the concentration of the high-Z material can range from about 45 wt% to about 50 wt%. In one aspect of the invention, the insulating material also contains substances that are known to  
10           optimize the thermal conductivity, such as metallic particles, or inclusions of high-thermal-conductivity materials.

          The x-ray device of the invention optionally contains shielding 80 for the operator. When in operation, x-rays can often backscatter from the object being analyzed, such as the teeth of a patient, and strike the operator. The shielding 80 is used to protect the operator from  
15           such aberrant radiation. In one aspect of the invention, the shielding used is a Pb-filled acrylic radiation scatter shield.

          The x-ray device of the invention also contains control means for operating the x-ray device. Any controls known in the art can be used in the control means of the invention. Examples of such controls include up and down arrow membrane switches with an LED  
20           readout to adjust exposure time. Indicators can include "power on," "start," and "x-rays on" LEDs. In the aspect of the invention illustrated in Figure 1, the control means (controller 70)

is integrated into the housing 20 of the device. In another aspect of the invention, the control means (such as controller 76) is external to the device and is connected to remainder of the device using any known electronic connection, such as cable 72 (See Figure 3). In either instance, the control means also contains a trigger 74 that is incorporated into the handle 15  
5 and used by the operator to begin (and conclude) the x-ray exposure.

The invention also contains means for detecting or sensing the x-rays. Any detecting means known in the art that is sensitive to x-ray radiation can be used in the invention. Examples of such detecting means include x-rays receptors, x-ray film, CCD sensors, CMOS sensors, TFT sensors, imaging plates, and image intensifiers. In one aspect of the invention,  
10 and as illustrated in Figure 10, a CCD sensor 50 is used as the detecting means in the x-ray devices of the invention.

The x-ray device may also contain means for displaying the x-rays detected by the detecting means. Any display means that displays the detected x-rays in a manner that can be understood by the operator of the device can be used for the invention. Examples of  
15 displaying means that can be used include film, imaging plates, and digital image displays such as cathode ray tubes (CRT) or liquid crystal display (LCD) screens. In one aspect of the invention, the display means can be used as a densitometer for the x-ray absorption.

In one aspect of the invention, the display means is integrated into the housing of the x-ray device. Such integration, however, will limit the size of the display means since too large  
20 a display means will detract from the portability of the device. In this aspect of the invention,

any small display means with sufficient resolution can be used in the invention, including liquid crystal display (LCD) screens 60.

In another aspect of the invention, the display means are located external to the x-ray device. In this aspect, a separate imaging plate (such as a CMOS or TFT plate) for larger features (such as medical or veterinary imaging) can be used. The separate imaging plate can be connected to the remainder of the x-ray device as known in the art.

In one aspect of the invention, and as illustrated in Figure 10, the x-ray device 10 can contain both a detecting means (such as CCD sensor 50), integrated display means (such as the LCD screen 60), and well as control means (such as controller 70). With these components, the size of the x-ray device can be minimized and the portability and uses of the x-ray device can be optimized.

The detecting means and the display means can be used to temporarily store images in the x-ray device. Once the storage capacity for these temporary images has been reached, an optional wired or wireless connection can then provide seamless update to an external electronic device or system, such as a permanent database or a desktop computer as known in the art. The wired or wireless connection can be made as known in the art. In one aspect of the invention, this connection is wireless since it provides true portability and freedom from line voltage.

In Figure 10, the detecting means (CCD sensor 50) is not structurally attached to the x-ray device 10. Thus, in this aspect of the invention, the detecting means is free standing. With some of the known portable x-ray devices, the detecting means is structurally attached to the x-

ray devices. Accordingly, the position of the detecting means is fixed relative to the rest of the x-ray device and when the x-ray device moves, so must the detecting means. This movement presents a problem for portable x-ray devices because any motion of the detecting means relative to the subject to be imaged result in distortion and blurring of the image. Because the detecting means of the invention is free-standing, any minor movements of the x-ray device of the invention will not result in distortion or blurring. As well, when the detecting means (i.e., a CCD sensor) is structurally attached, the x-ray device is typically configured to work with that specific type (e.g., size, shape) of the CCD sensor. The free-standing detecting means, however, can be interchanged with any given x-ray device without having to substantially modify the x-ray device.

In Figure 10, the detecting means (i.e., CCD sensor 50) communicates with the x-ray device 10 by any known wireless transmission mechanism. Examples of some wireless transmission mechanisms include 802.11 protocols, wireless application protocols (WAP), Bluetooth technology, or combinations thereof. In one aspect of the invention, Bluetooth technology is used as the wireless transmission mechanism. The radiographic image detected by the detecting means (CCD sensor 50) is transmitted to the x-ray device 10 and then viewed via the display means 60.

The free-standing detecting means can be customized for analyzing any type of object. In one aspect of the invention, the CCD sensor can have non-flat configurations. In other aspects of the invention, the CCD sensor can have different types of shapes (other than the square illustrated in the Figures), such as rectangular, circular, oblong, polygonal, etc.... To

achieve larger image areas, arrays of multiple detecting means can be assembled with electronics to resemble a single detecting means with the desired larger area.

With the free-standing detecting means in this aspect of the invention, the x-ray device 10 is especially useful in the dental industry. As illustrated in Figure 11, the x-ray device 10 can be used to analyze a tooth 90 (or multiple teeth) of a patient by placing the tooth 90 between the x-ray device 10 and the CCD sensor 50 and then operating the device. In Figure 11, the CCD sensor 50 is connected to the x-ray device 10 by using any known wiring 55 (or cable) for that sensor to transmit the radiographic image to the x-ray device 10. A similar aspect of the invention is illustrated in Figure 12, except that the wiring 55 has been replaced with wireless technology.

In a similar aspect of the invention, the x-ray device can be modified slightly to be used in medical industry. In this aspect of the invention, the size of the detecting means (i.e., CCD sensor or CMOS imaging plate) is increased to capture a larger radiographic image. The larger size would depend on the part of the body that is being analyzed, as well as the maximum field size of the x-ray device. Typically, the size of the detecting means can range up to about 24 inches. In one aspect of the invention, the size of the detecting means can range from about 10 to about 14 inches.

The x-ray device of the invention can also be configured differently in another aspect of the invention as shown in Figure 13-16. In this aspect of the invention, the x-ray device 110 contains the same components as x-ray device 10, has been configured to look substantially

like a traditional camera. This gives the impression to the operator of the x-ray device 110 that it operates like it looks: a camera, but for capturing digital radiological images.

As shown in Figure 13-16, the x-ray device 110 contains housing 120 that is substantially rectangular in shape. In this aspect of the invention, the housing 120 does not contain a handle. Rather, the housing 120 can contain a protruding shape 122 that provides the operator with a better grip than a flat surface. Of course, the x-ray device 110 could contain similar features for the handling and operation of the device, such as texturing the surface for easier gripping or by providing indentations.

Like the x-ray device 10, the x-ray device 110 contains similar internal components such as an x-ray tube and an integrated power system. These internal components operate in substantially the same manner as x-ray device 10, but have been configured within the housing 120 to accommodate a different shape. As well, the x-ray device 110 contains control means (not shown), including trigger 174, radiation shielding 180, and any other components known in the art for efficient operation (such as x-ray collimator 132), including those components described in the documents mentioned above.

The x-ray device 110 also contains means for displaying the results of the analysis. In this aspect of the invention, the x-ray device 110 contains an integrated display means, like LCD screen 160. As shown in Figure 16, the removeable LCD screen 160 is configured to fit easily within a hollow portion 176 in the rear of the device 110 where it can be easily viewed by the operator. Of course, external display means could also be used in the invention.



In one aspect of the invention, the display means and the control means are combined into a single means: a controllable display means. The controllable display means controls the operation of the x-ray device, as well as controls and manipulates the image display. The controllable display means can be either integrated into the x-ray device 110 or can be external to the x-ray device 110. Any controllable display means known in the art that operates in this manner can be used in the invention. One example of a controllable display means comprises a portable electronic device 165, such as a personal digital assistant (PDA), a handheld computer (like an IPAQ), or a conventional camera-style LCD screen.

Using the portable electronic device with the x-ray device provides improved flexibility. For example, the portable electronic device—including both the hardware and the software—can be upgraded without needing to change the x-ray device itself. As well, the software in the portable electronic device can be used for image analysis, image enhancement, and for diagnosis at the point of image capture. Further, the x-ray device can be upgraded or modified with having to change the portable electronic device. Indeed, the portable electronic device could be customized so that any individual could take the customized settings and use them with any similar x-ray device.

The controllable display means can be connected to the x-ray device 110 by wired or wireless technology. As shown in Figure 17, the x-ray device 110 (including hollow portion 176) could be adapted to contain conventional interfaces in the hollow portion 176 for a portable electronic device 165. Thus, the portable electronic device 165 is mechanically and electrically connected to the x-ray device when placed in hollow portion 176. As well, the

portable electronic device 165 could be electrically connected to the x-ray device 110 using conventional wiring. Finally, the portable electronic device 165 could be remotely connected to the x-ray device using any conventional wireless technology.

Using the portable electronic device with the x-ray device 110 also increases the  
5 functionality of the x-ray device. For example, the portable electronic device could contain a temporary patient database. With flash memory storage devices, the patient database could be located on the portable electronic device and accessed when using the x-ray device. In another example, imaging software on the portable electronic device could allow for determining and manipulating features in the image, such as dental carries (cavities), breaks in bones, cracks in  
10 welds or pipes, identification of suspect shapes in security imaging, etc...

Indeed, any function currently performed on a desktop computer or workstation could be performed right at the x-ray device, including contrast enhancement, image sharpening, smoothing, reverse shading, assignment of colors for different density materials, determination of relative densities, etc.... All of these functions, as well as others, could be performed with the  
15 portable electronic device attached to the x-ray device, or with it operating remotely. The portable electronic device could then interface with any known external electronic device (such as a storage device, office computer, or workstation) using wired or wirelessly technology to transfer data and/or information. As well, the portable electronic device (and therefore the x-ray device) could utilize the additional capabilities provided by the external electronic device.

20 The x-ray devices of the invention can be made in any manner that provides the device with the components in this configuration described above. The housing, x-ray tube, detection means,

display means, control means, radiation shielding, power source, and conversion means can be provided as known in the art and as described in the publications disclosed above. The insulating material can be made by mixing the needed amount of high-Z substance (such as an oxide of a heavy metal) into the insulating material (such as the silicone potting material when the A and B parts of the silicone are mixed together). The resulting combination is thoroughly mixed, and then uniformly provided around the x-ray tube, such as by pouring into an encapsulating mold. In this way, the insulating material containing the high-Z substance is uniformly distributed throughout the layer surrounding the x-ray tube.

When making the power supply, the process will be illustrated with two individual power supplies. Each power supply is configured so that the grounded ends of each power supply are located near the center of the x-ray tube. The positive voltage from one supply is provided to one side of the x-ray tube, and the negative voltage from the other supply is provided to other end of the x-ray tube. In this configuration, the maximum voltage (i.e., the sum of both) can be isolated from each individual power supply along the full length of the x-ray tube and the isolation from ground only needs to be  $\frac{1}{2}$  of the total voltage. Consequently, the insulating paths need only be  $\frac{1}{2}$  the length.

The x-ray device can be operated in any manner that provides a radiographic image. In one aspect of the invention, the x-ray device 10 (or 110) of the invention can be operated by first actuating the appropriate button on the control means to turn on the device. After setting the exposure time, an "enable" button is pressed. This "enable" acts as a safety switch, preventing

initiation of the x-ray exposure until the operator has positioned the instrument in the correct location and prepares to pull the trigger.

Then, on pulling the trigger (or pressing the "start" button) the high voltage (HV) supplied by the power supply 34 will increase up to about 70kV (i.e., one power supply at about +35kV and the other at about -35kV). When this HV level is reached, the filament will energize at its full setpoint to supply the needed emission current to the x-ray tube. The filament will remain at this level for the time designated by the operator (i.e., by using the controls). The start indicator in the LED of the control means can illuminate upon pressing the trigger. The "x-rays on" indicator in the LED of the control means can illuminate during the entire time that the emission current for the x-ray tube is present. Additionally, an audible signal can be used to indicate that the x-rays are being emitted.

During exposure after pressing the trigger 74 (or 174), x-rays are emitted from the x-ray tube 30 and strike the object being analyzed, i.e., the teeth of a patient when the x-ray device is being used for dental purposes. To meet x-ray equipment standards, the button or trigger 74 (or 174) must be held down during the full length of the exposure. During exposure, the x-rays are used for analysis of the object as known in the art by using the detection means. The operator can then view the results of the analysis in the display means and optionally download the images to an external electronic device.

Following the exposure of a patient with the x-rays, the filament will turn off (along with the "x-rays on" indicator) and the HV will ramp down. Once the HV is off, the start indicator in the LED of the controller will turn off and the x-ray device will return to a standby condition. In

one aspect of the invention, the operator may need to re-enter the exposure time before starting the next exposure. This re-entering process can be accomplished with a "ready" indicator in the LED of the control means after the exposure time has been set.

5 The x-ray device of the invention can be modified to contain additional optional features, including any of those described in the publications mentioned above. For example, to increase battery life, the x-ray device can contain an automatic shut off feature that shuts the device off after 2 minutes without an x-ray exposure. Another feature that can be added, for example, is to manufacture the housing or chassis 20 (or 120) of a high-impact material (such as ABS or a plastic alloy of ABS and other materials, designed for high-impact resistance) to reduce the risk  
10 of damage.

The x-ray device of the invention can also be made as part of a system for x-ray analysis. The system could contain any components that aid in the operation of the x-ray device or the x-ray analysis, including those mentioned above such as an external means for storing the radiographic images. As well, the system could also include a hard-side carrying case, an  
15 "industrial strength" tripod, a 3 meter long umbilical cord to a remote control panel 76, or the like. The system could also contain a back-up power source 40. Finally, the system could also contain any of those components described in the documents mentioned above.

Using the x-ray device of the invention provides several improvements over conventional devices. First, the x-ray device of the invention contains an integrated power system. The power  
20 system can be battery-operated, yet still provide a continuous high voltage, rather than Marx generators (pulsed) or capacitively-pulsed systems. Thus, the x-ray device can maintain a

continuous DC high voltage supply and can generate a high voltage for a few seconds with each high current discharge. The high storage capacity provided by the batteries allows hundreds of discharges, anywhere from about 10 to about 20 amps for a few seconds. For most applications, including for dental purposes, the x-ray devices of the invention need less than a second for each exposure.

Most conventional x-ray devices, however, have external power supplies. Those conventional x-ray devices that do have integrated power supplies, still don't have the high current load described above. Thus, the power system of the invention can provide a constant radiation output and improved image quality while reducing the x-ray dosage to which the object (i.e., patient) is exposed.

Another improvement in the x-ray devices of the invention exists in the shielding for the x-ray tubes. Conventional x-ray tubes are shielded with a liquid oil encasement and lead shielding, both of which are bulky and heavy. Both of these components are eliminated in the x-ray tube shielding of the invention. Instead, the shielding of the invention contains a low-density insulating material that contains high-Z substances. This configuration leads to reduced material count and generally lower weight.

Other improvements result from the free-standing detecting means and the portable electronic device. With the free-standing detecting means, better images can be obtained even if the x-ray device moves. As well, the free-standing detecting means is more interchangeable with the x-ray device. When the portable electronic device is used with the x-ray device, the

functionality (i.e., image display and manipulation) and interchangeability of the devices is greatly improved.

In addition to any previously indicated variation, numerous other modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention and appended claims are intended to cover such modifications and arrangements. Thus, while the invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred aspects of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including but not limited to, form, function, manner of operation and use may be made without departing from the principles and concepts set forth herein.